US009971162B2

(12) **United States Patent**
Banerjee et al.

(10) **Patent No.: US 9,971,162 B2**
(45) **Date of Patent: May 15, 2018**

(54) **APPARATUSES AND METHODS FOR MAKING AN OBJECT APPEAR TRANSPARENT**

(71) Applicant: **Toyota Motor Engineering & Manufacturing North America, Inc.**, Erlanger, KY (US)

(72) Inventors: **Debasish Banerjee**, Ann Arbor, MI (US); **Hideo Iizuka**, Nissin (JP)

(73) Assignee: **Toyota Motor Engineering & Manufacturing North America, Inc.**, Plano, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 74 days.

(21) Appl. No.: **15/185,988**

(22) Filed: **Jun. 17, 2016**

(65) **Prior Publication Data**

US 2017/0227781 A1 Aug. 10, 2017

Related U.S. Application Data

(60) Provisional application No. 62/291,920, filed on Feb. 5, 2016.

(51) **Int. Cl.**
G02B 27/14 (2006.01)
G02B 27/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G02B 27/14*** (2013.01); ***B60R 13/025*** (2013.01); ***G02B 5/3083*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC G02B 5/30; G02B 5/3025; G02B 5/3083; G02B 21/14; G02B 27/024;
(Continued)

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,684,255 A * 8/1987 Ford G01J 3/453 356/455
5,941,596 A 8/1999 See
(Continued)

OTHER PUBLICATIONS

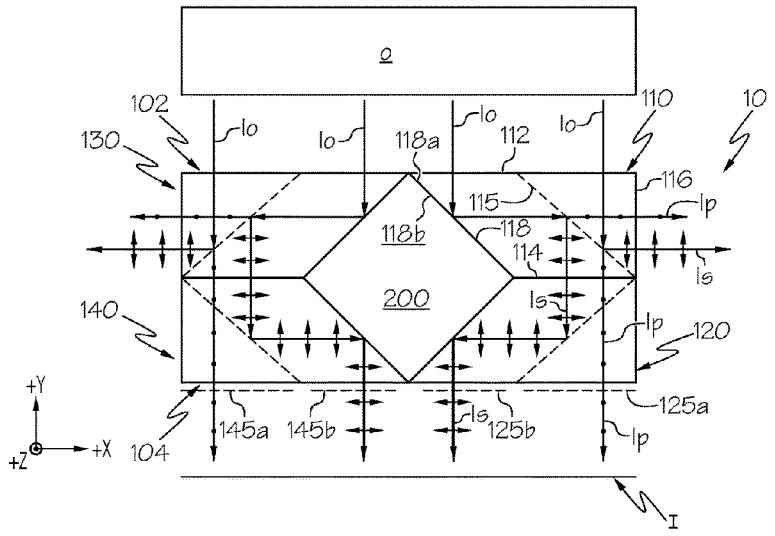
Hongsheng Chen et al., "Broadband polygonal invisibility cloak for visible light", Scientific Reports, Feb. 9, 2012, pp. 1-14.
(Continued)

Primary Examiner — Loha Ben
(74) *Attorney, Agent, or Firm* — Dinsmore & Shohl LLP

(57) **ABSTRACT**

A cloaking device includes cloaking region boundary planes oriented non-planar to each other, each of the cloaking region boundary planes having an outward facing mirror surface and an inward facing opaque surface. The cloaking device includes a cloaking region bounded at least partially by the inward facing opaque surfaces of the cloaking region boundary planes. Half mirrors are spaced apart from and generally parallel to the outward facing mirror surfaces such that a half mirror is spaced apart from and generally parallel to each outward facing mirror surface. Light from an object on an object-side of the cloaking device is directed around an article within the cloaking region and forms an image on an image-side of the cloaking device such the article appears transparent to an observer looking towards the object.

20 Claims, 9 Drawing Sheets



(51) **Int. Cl.**

G02B 27/28	(2006.01)
G02B 5/30	(2006.01)
B60R 13/02	(2006.01)
B60R 1/08	(2006.01)

(52) **U.S. Cl.**

CPC ***G02B 27/1086*** (2013.01); ***G02B 27/283*** (2013.01); *B60R 1/082* (2013.01); *B60R 2013/0287* (2013.01); *G02B 5/30* (2013.01); *G02B 5/3025* (2013.01); *G02B 27/144* (2013.01)

(58) **Field of Classification Search**

CPC .. G02B 27/1086; G02B 27/14; G02B 27/141; G02B 27/143; G02B 27/144; B60R 1/08; B60R 1/082; B60R 13/02; B60R 13/025; B60R 2013/0287; G03B 21/2066; G03B 21/2073

USPC 359/299–304, 493, 618, 629, 634; 396/331, 386, 544; 353/12, 14, 20, 28, 353/66

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,982,343	A *	11/1999	Iba	G02B 27/0172 345/8
6,130,784	A *	10/2000	Takahashi	H04N 5/7491 348/E5.145
2015/0248013	A1	9/2015	Chen et al.	

OTHER PUBLICATIONS

John C. Howell et al., "Simple, broadband, optical spatial cloaking of very large objects", Department of Physics and Astronomy, University of Rochester, www.physics.optics, arXiv:1306.0863 </abs/1306.0863> [physics.optics], Jun. 2013.

Yihao Yang et al., "Towards omnidirectional, large scale, full polarization, and broadband practical invisibility cloaks: challenges and progress", EPJ Appl. Metamat. 2014, 1, 7.

"Physics demonstrations: cloaking device?", Apr. 25, 2013; URL: https://skullsinthestars.com/2013/04/25/physics-demonstrations-cloaking-device.

* cited by examiner

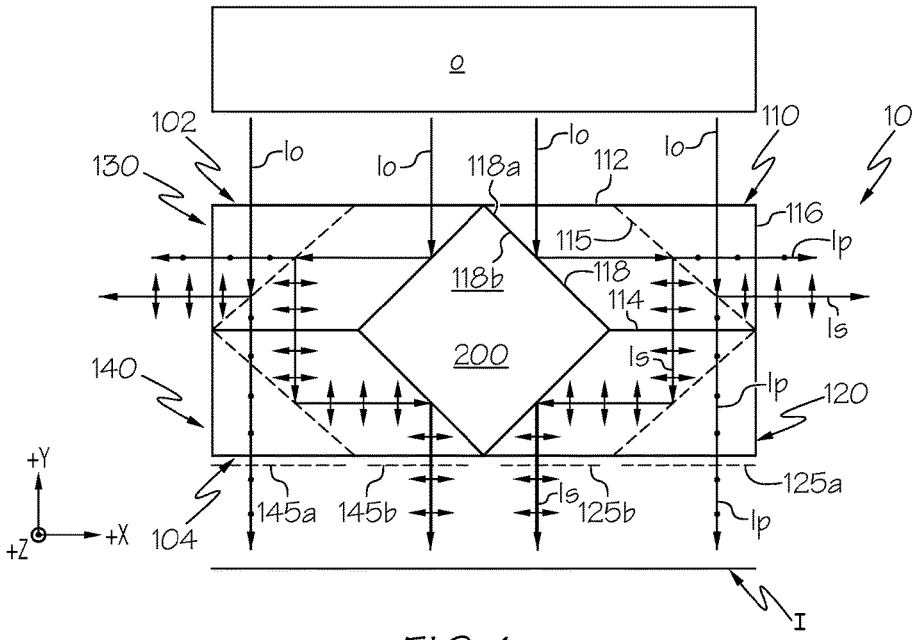

o
102
130
Io
Io
118a
Io
112
110
10
116
115
Ip
118b
118
114
Is
200
Is
140
Ip
120
125a
145a
145b
Is
125b
Ip
104
+Y
+X
+Z
I

FIG. 1

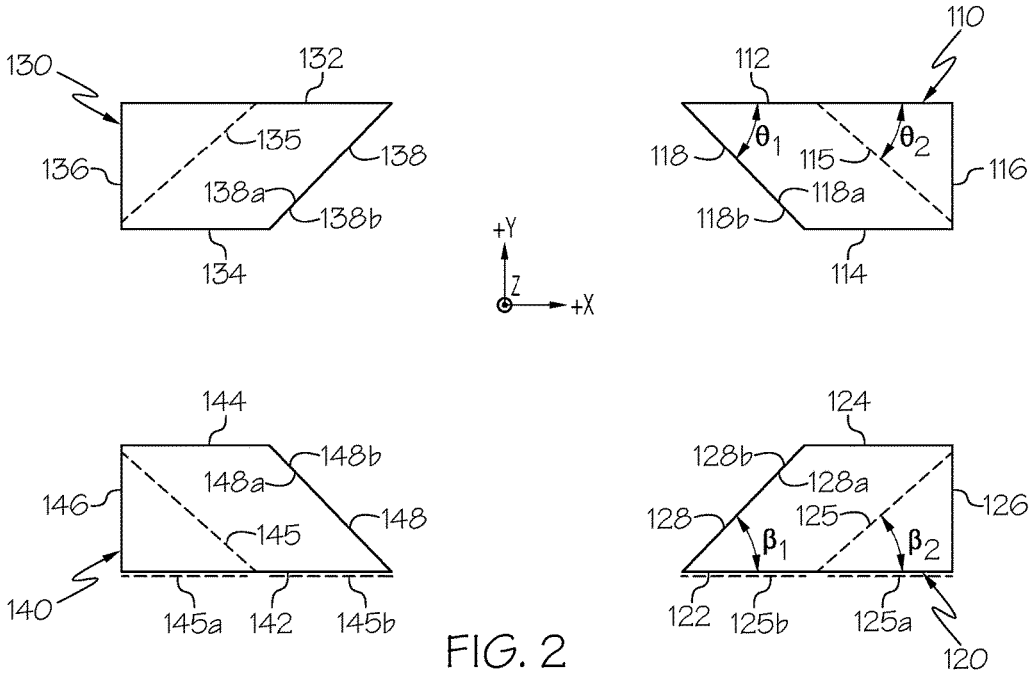

130
132
135
138
136
138a
138b
134
110
112
θ1
θ2
118
115
116
118a
118b
114
+Y
Z
+X
144
148b
148a
146
148
145
140
145a
142
145b
124
128b
128a
126
128
125
β1
β2
122
125b
125a
120

FIG. 2

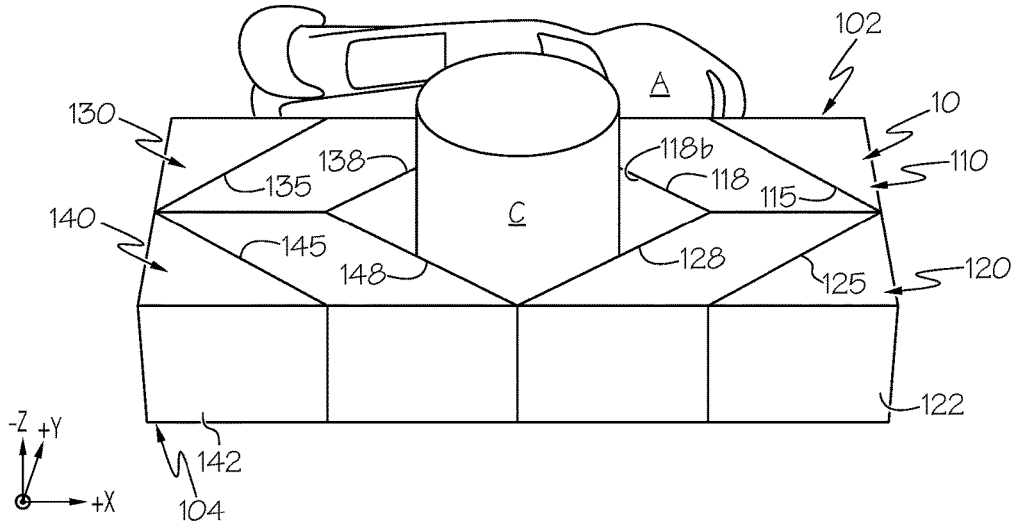

102
A
10
130
138
118b
110
135
118
115
C
140
145
148
128
125
120
122
-Z +Y
+X
142
104

FIG. 3

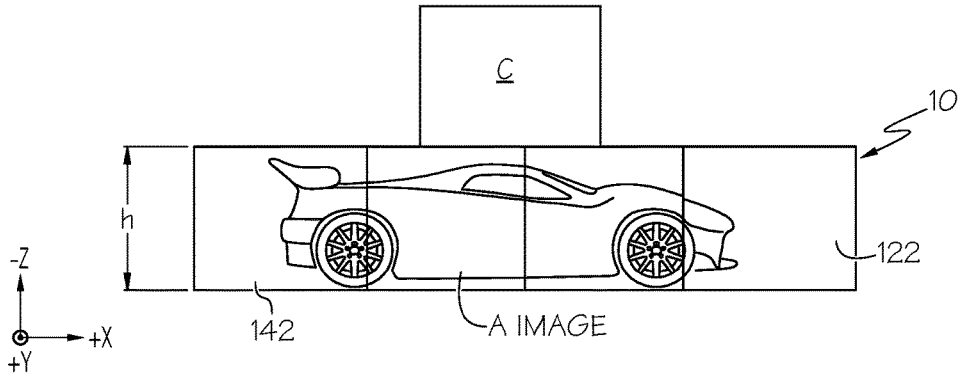

C
10
h
122
-Z
+X
+Y
142
A IMAGE

FIG. 4

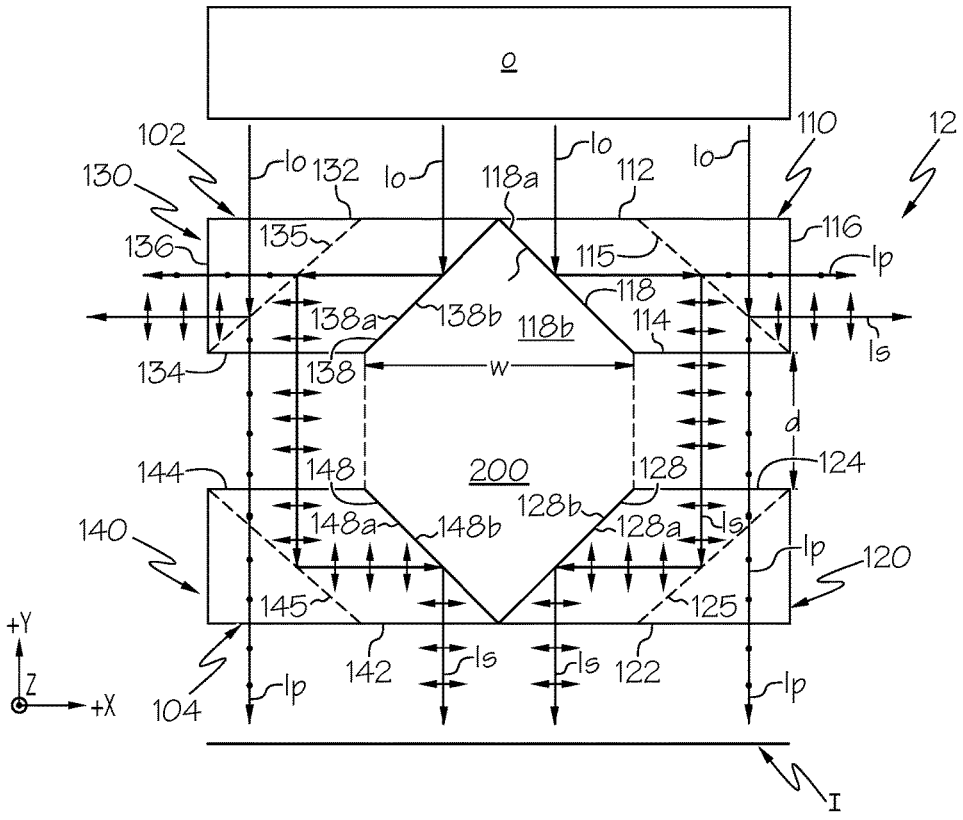

o
102
130
136
134
132
135
lo
118a
112
110
12
116
lp
115
118
114
ls
138a
138b
118b
138
w
d
144
148
200
128
124
140
148a
148b
128b
128a
120
145
125
142
122
104
+Y
Z
+X
I

FIG. 5

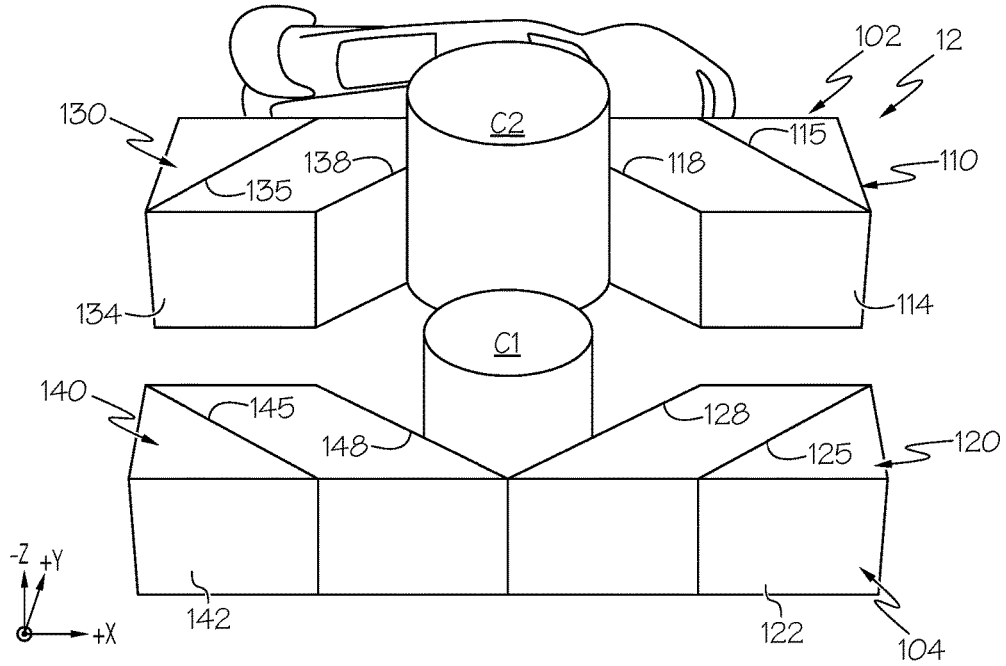

102
12
130
C2
115
138
118
110
135
134
114
C1
140
145
128
148
125
120
-Z
+Y
+X
142
122
104

FIG. 6

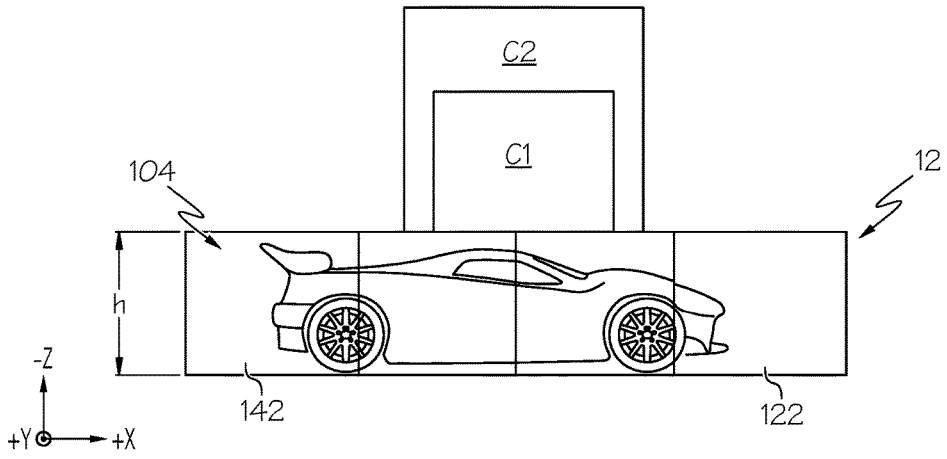

C2
C1
104
12
h
-Z
+Y
+X
142
122

FIG. 7

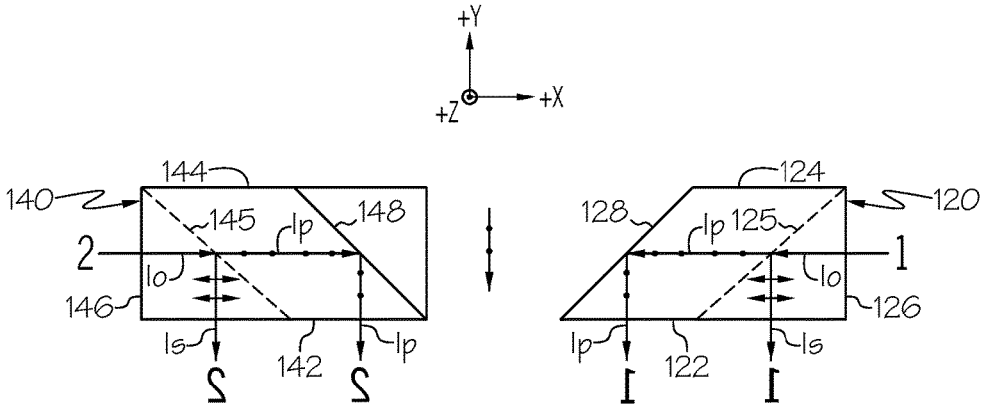


FIG. 8

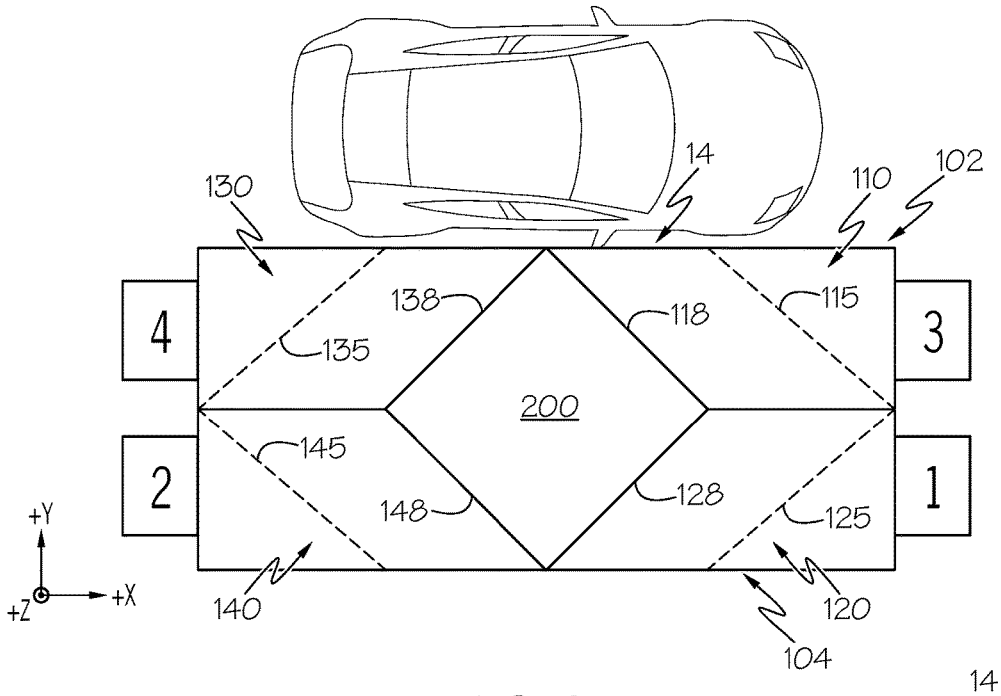


FIG. 9

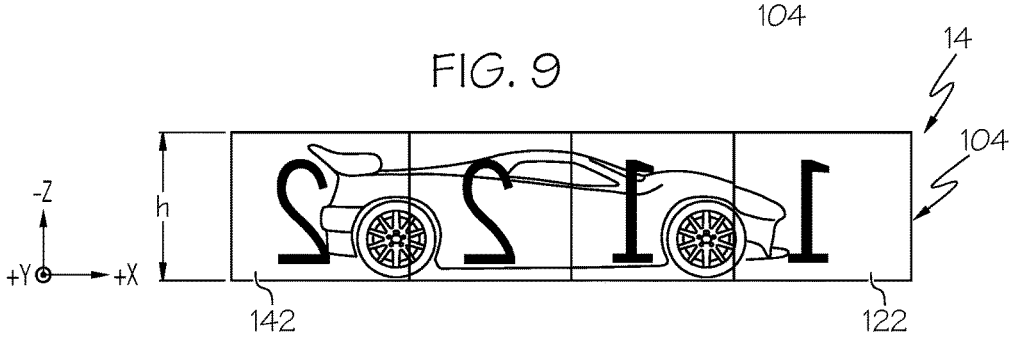


FIG. 10

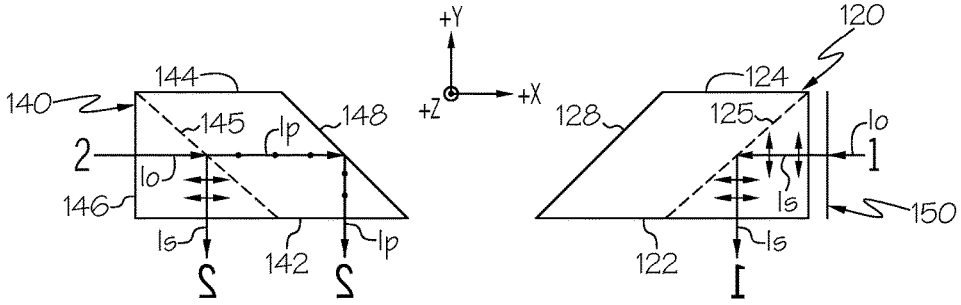


FIG. 11

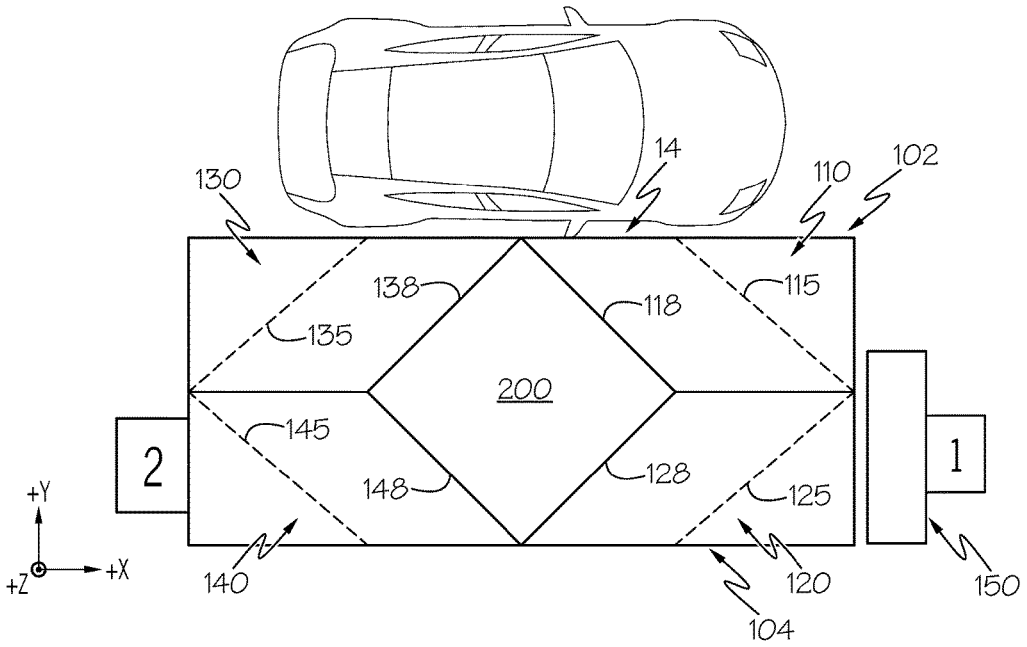


FIG. 12

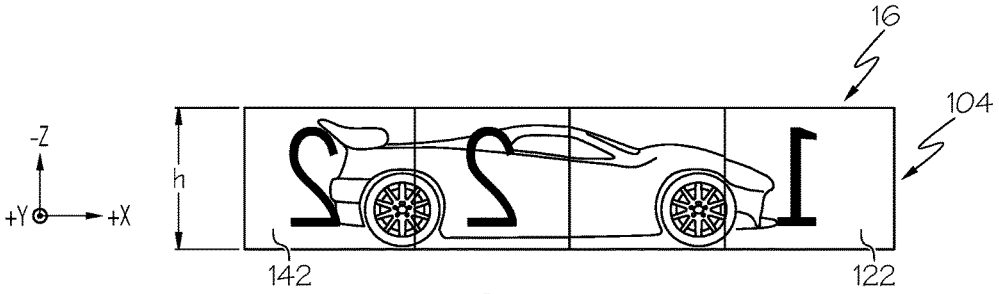


FIG. 13

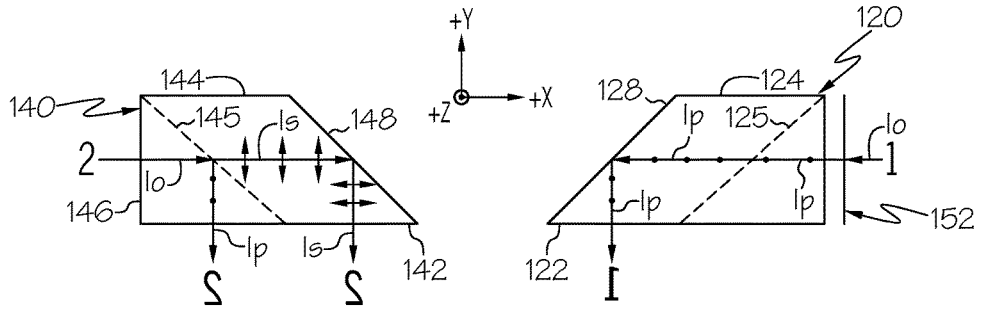


FIG. 14

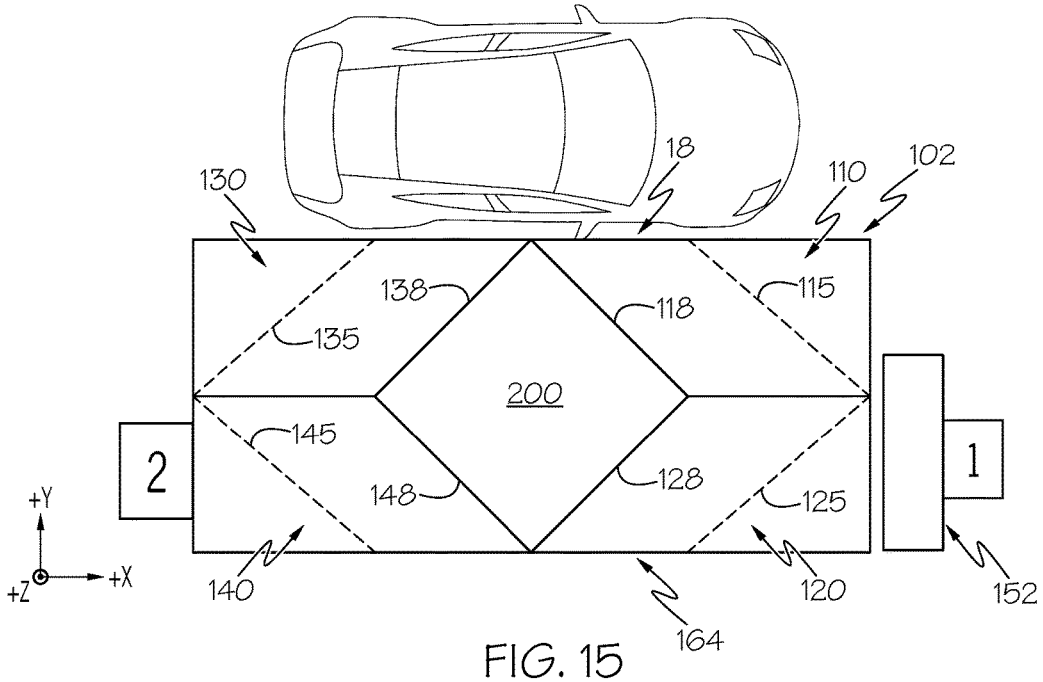


FIG. 15

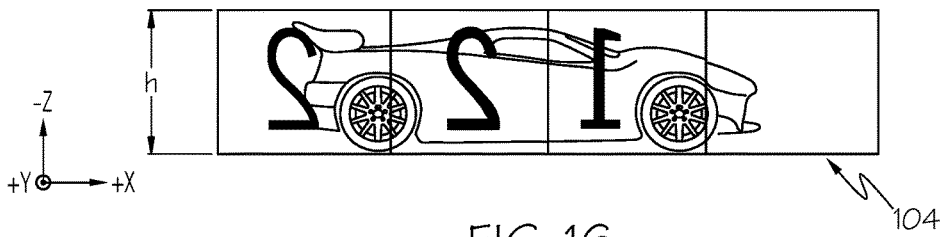


FIG. 16

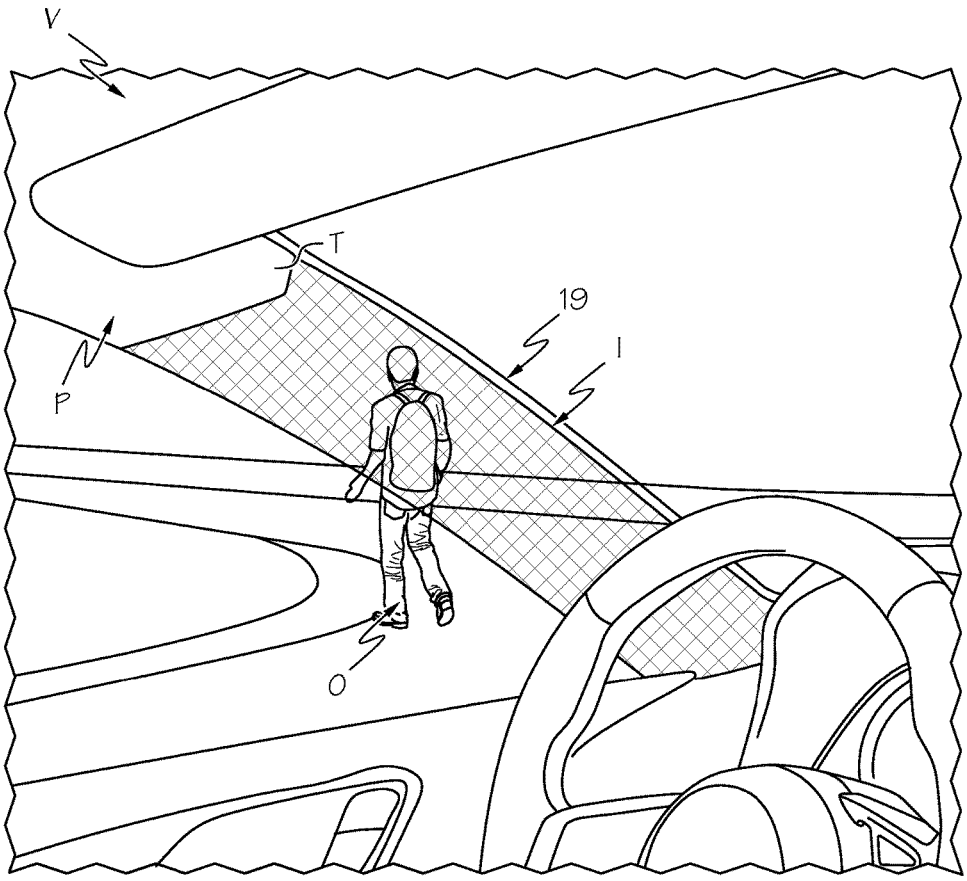


FIG. 17

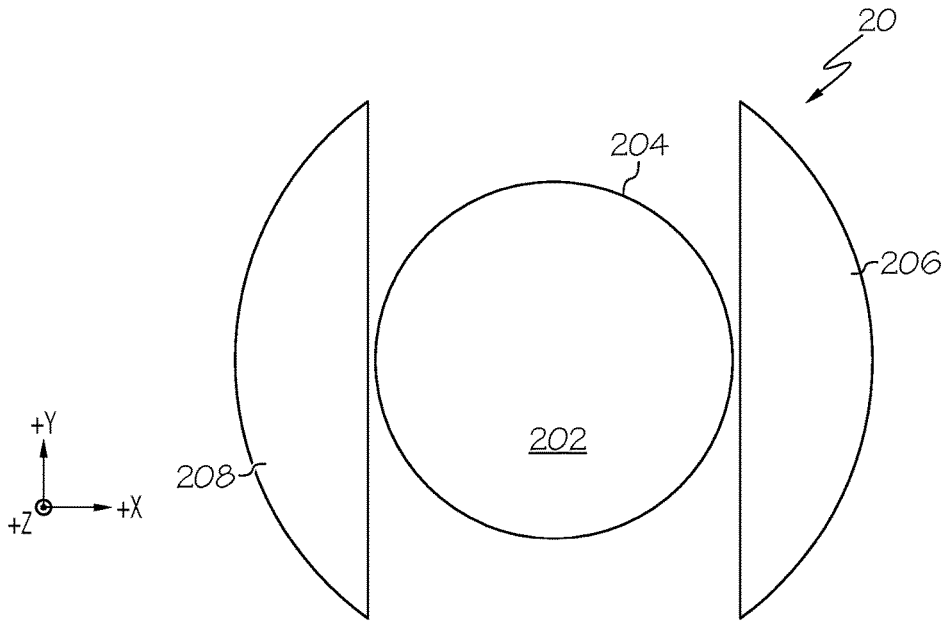


FIG. 18

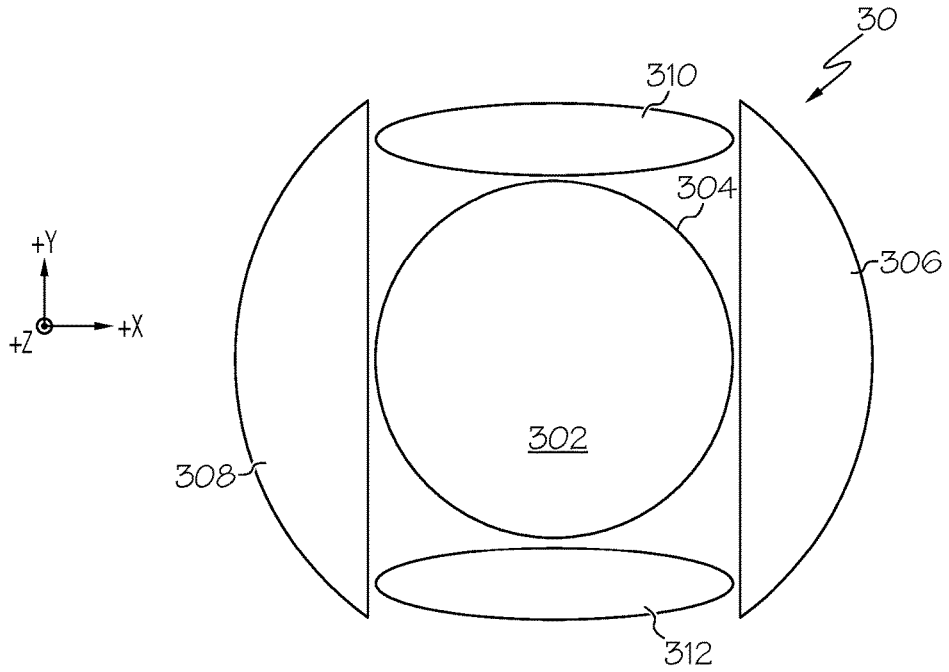


FIG. 19

APPARATUSES AND METHODS FOR MAKING AN OBJECT APPEAR TRANSPARENT

RELATED APPLICATION

This application claims the benefit of U.S. Provisional Patent Application Ser. No. 62/291,920 filed Feb. 5, 2016, the entirety of which is incorporated herein by reference.

TECHNICAL FIELD

The present specification generally relates to apparatuses and methods for making an object appear transparent and, more specifically, to cloaking devices for pillars of vehicles and methods for making pillars of vehicles appear transparent.

BACKGROUND

Studies on cloaking devices that appear to make a pillar of a vehicle transparent have been published. Such studies disclose the use of metamaterials or the use of video cameras in combination with a display screen to allow an occupant of a vehicle to ostensibly "see" though the vehicle pillar, thereby reducing blind spots in the vehicle. However, metamaterials and video technology use complicated material designs and equipment.

Accordingly, a need exists for alternative devices that appear to make a pillar of a vehicle transparent.

SUMMARY

In one embodiment, a cloaking device includes cloaking region (CR) boundary planes oriented non-planar to each other and each of the CR boundary planes has an outward facing mirror surface and an inward facing opaque surface. The cloaking device includes a CR at least partially bounded by the inward facing opaque surfaces of the CR boundary planes. The cloaking device includes half mirrors spaced apart from and generally parallel to the outward facing mirror surfaces such that a half mirror is spaced apart from and generally parallel to each outward facing mirror surface. An article positioned within the CR is not visible outside of the CR and light reflected from an object on one side of the cloaking device is redirected around the CR and the article positioned within the CR, and forms an image of the object on another side of the cloaking device.

According to another embodiment, a cloaking device for cloaking an article of a vehicle includes a cloaking assembly with an object-side, an image-side and at least two CR boundary planes positioned at least partially between the object-side and the image-side. The at least two CR boundary planes are positioned non-planar to each other and each of the at least two CR boundary planes have an outward facing mirror surface and an inward facing opaque surface. A CR is bounded by the inward facing opaque surfaces of the at least two CR boundary planes and a vehicle article positioned within the CR is not visible from outside the CR. The cloaking assembly has at least two half mirrors positioned at least partially between the object-side and the image-side. Each of the at least two half mirrors is spaced apart from and generally parallel to one of the outward facing mirror surfaces such that a half mirror is spaced apart from and generally parallel to each outward facing mirror surface. Light from an object located on the object-side of the cloaking assembly, and obscured by the vehicle article positioned within the CR is redirected around the CR, and forms an image of the object on the image-side of the cloaking assembly such that the vehicle article appears transparent to an observer looking in a direction towards the object.

In embodiments, the cloaking assembly has four CR boundary planes and four half mirrors. The four CR boundary planes are oriented generally orthogonal to each other, the CR is bounded by the four CR boundary planes, and each of the half mirrors are spaced apart and generally parallel to one of the outward facing mirror surfaces such that a half mirror is spaced apart and generally parallel to each outward facing mirror surface. Each of the half mirrors may be selected from a p-polarization half mirror or an s-polarization half mirror. Light reflected from the object located on the object-side of the cloaking assembly passes through the cloaking assembly by reflecting off of a first outward facing mirror surface, a first half mirror oriented generally parallel to the first outward facing mirror surface, a second half mirror oriented generally orthogonal to the first half mirror and a second outward facing mirror surface oriented generally parallel to the second half mirror. Light that passes through the cloaking assembly forms an image of the object on the image-side of the cloaking assembly.

In embodiments, the cloaking device with the cloaking assembly has an end surface oriented non-planar to a half mirror. Light from an item located adjacent to the end surface passes through the cloaking assembly and forms an image of the item on the image side of the cloaking assembly.

These and additional features provided by the embodiments described herein will be more fully understood in view of the following detailed description in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The embodiments set forth in the drawings are illustrative and exemplary in nature and not intended to limit the subject matter defined by the claims. The following detailed description of the illustrative embodiments can be understood when read in conjunction with the following drawings, where like structure is indicated with like reference numerals and in which:

FIG. **1** schematically depicts a top view of a cloaking device according to one or more embodiments described and illustrated herein;

FIG. **2** schematically depicts top isolated views of four cloaking device components of the cloaking device of FIG. **1** according to one or more embodiments described and illustrated herein;

FIG. **3** schematically depicts a top perspective view of the cloaking device of FIG. **1** with a first object on one side of the cloaking device and a second object within a cloaking region (CR) of the cloaking device;

FIG. **4** schematically depicts a side view of the cloaking device of FIG. **3** with the first object on one side of the cloaking device and the second object within the CR of the cloaking device;

FIG. **5** schematically depicts a top view of a cloaking device according to one or more embodiments described and illustrated herein;

FIG. **6** schematically depicts a top perspective view of the cloaking device of FIG. **5** with a first object on one side of the cloaking device and a second object and a third object within a CR of the cloaking device;

FIG. **7** schematically depicts a side view of the cloaking device of FIG. **6** with the first object on one side of the cloaking device and the second object and the third object within the CR of the cloaking device;

FIG. **8** schematically depicts a top isolated view of two cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **9** schematically depicts a top view of a cloaking device with four cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **10** schematically depicts a side view of the cloaking device shown in FIG. **9**;

FIG. **11** schematically depicts a top isolated view of two cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **12** schematically depicts a top view of a cloaking device with four cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **13** schematically depicts a side view of the cloaking device of FIG. **12**;

FIG. **14** schematically depicts a top isolated view of two cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **15** schematically depicts a top view of four cloaking device components according to one or more embodiments described and illustrated herein;

FIG. **16** schematically depicts a side view of the cloaking device of FIG. **15**;

FIG. **17** schematically depicts a side view of a cloaking device cloaking an A-pillar of a vehicle according to one or more embodiments described and illustrated herein;

FIG. **18** schematically depicts a top view of a cloaking device according to one or more embodiments described and illustrated herein; and

FIG. **19** schematically depicts a top view of a cloaking device with four cloaking device components according to one or more embodiments described and illustrated herein.

DETAILED DESCRIPTION

A cloaking device is provided. The cloaking device may have an object-side, an image-side and a cloaking region (CR) boundary plane having an outward facing mirror surface and an inward facing opaque surface. A CR is at least partially bounded by the inward facing opaque surface of the CR boundary plane and a half mirror is spaced apart from and generally parallel to the outward facing mirror surface. The half mirror may be a p-polarization half mirror or an s-polarization half mirror. In embodiments, an article, e.g. an A-pillar of a vehicle, a B-pillar of a vehicle or a C-pillar of a vehicle, is positioned within the CR and light from an object located on the object-side of the cloaking device and obscured by the CR is redirected around the CR and the article and forms the image of the object on the image-side of the cloaking device such that the article appears transparent. Various embodiments of cloaking devices and methods for using the same will be described in further detail herein with specific reference to the appended drawings.

FIG. **1** generally depicts one embodiment of a cloaking device. The cloaking device includes a cloaking region (CR) that is at least partially bounded by at least two CR boundary planes that are non-planar to each other. Each of the two CR boundary planes has an outward facing mirror surface and an inward facing opaque surface. Spaced apart from and oriented generally parallel to each of the CR boundary planes is a half mirror (e.g., a polarizing half mirror) that allows p-polarized light to pass through and s-polarized light to be reflected or, alternatively, allows s-polarized light to pass through and p-polarized light to be reflected. Referring to the coordinate system in the figure, portions of a target object are located directly behind the CR in the +Y direction (obscured portions of the object which are otherwise not visible through the CR) and portions of the target object are located outside or beyond the CR in the +Y direction (visible portions of the object). Light rays (light) from the obscured portions of the target object travel in the −Y direction and are incident on a first outward facing mirror surface. The first outward facing mirror surface reflects the incident light from the obscured portions of the target object in the +X direction to a first half mirror that is spaced apart from and oriented generally parallel to the first outward facing mirror surface. One mode of polarized light (e.g., p-polarized light) from the light reflected from the first outward facing mirror surface passes through the first half mirror (continues traveling in the +X direction), while another mode of polarized light (e.g. s-polarized light) is reflected by the first half mirror in the −Y direction. The polarized light reflected in the −Y direction by the first half mirror is reflected into the −X direction by a second half mirror. The polarized light reflected into the −X direction by the second half mirror is reflected in the −Y direction by a second outward facing mirror surface that is spaced apart from and oriented generally parallel to the second half mirror. An observer looking at the cloaking device in the +Y direction will see the reflection of the polarized light by the second outward facing mirror surface, i.e. polarized light originating from light from obscured portions of the target object will be visible to a human eye located on an opposite side of the CR from the obscured portions of the target object. Also, light reflected from an article positioned within the CR (i.e., the cloaked article) is not transmitted through the inward facing opaque surfaces and is not seen by the observer looking at the cloaking device in the +Y direction. That is, the cloaking device effectively redirects light from the obscured portions of the target object around the CR such that the light from the target object appears to pass through the cloaked article giving the visual impression that the cloaked article is not present. Light from the visible portions of the target object travels in the −Y direction and is incident on the first half mirror. One mode of the incident light (e.g., s-polarized light) is reflected in the +X direction by the first half mirror and another mode of the incident light (e.g. p-polarized light) is transmitted through the first half mirror and continues traveling in the −Y direction. The transmitted polarized light traveling in the −Y direction reaches the second half mirror and is transmitted through the second half mirror. An observer looking at the cloaking device in the +Y direction will see the transmitted polarized light traveling in the −Y direction, i.e. polarized light originating from light from visible portions of the target object will be visible to a human eye located on an opposite side of the cloaking device from the visible portions of the target object. Accordingly, an individual will see the entire target object, both obscured portions and visible portions, that is located on the opposite side of the CR (and thus on the opposite side of a cloaked article) giving the visual impression that the cloaked article is transparent.

Referring now to FIGS. **1-2**, embodiments of a cloaking device include a cloaking assembly **10** with four CR boundary planes **118**, **128**, **138**, **148**. The CR boundary planes **118**, **128**, **138**, **148** located adjacent to each other are non-planar to each other. In embodiments, opposing CR boundary planes **118**, **148** and **128**, **138** may be oriented parallel to each other and adjacent CR boundary planes **118**, **128**, **138**,

148 may be oriented orthogonal to adjacent CR boundary planes, e.g. CR boundary plane **118** is oriented orthogonal to adjacent CR boundary planes **138**, **128**, CR boundary plane **128** is oriented orthogonal to adjacent CR boundary planes **118**, **148**, etc. Each of the four CR boundary planes has an outward facing mirror surface **118***a*, **128***a*, **138***a*, **148***a*, respectively, and an inward facing opaque surface **118***b*, **128***b*, **138***b*, **148***b*, respectively. The outward facing mirror surfaces **118***a*, **128***a*, **138***a*, **148***a*, can be made from omni-directional photonic crystals or mirrors such that approximately 100% (+/−10%) of light incident on the outward facing mirror surfaces is reflected from the outward facing mirror surfaces. Accordingly, the term "mirror surface" used herein refers to a surface that reflects approximately 100% (+/−10%) of all modes of light (e.g. s-polarized light and p-polarized light) incident on the mirror surface. In embodiments, the CR boundary planes **118**, **128**, **138**, **148** form a CR **200** bound at least partly by the inward facing opaque surfaces **118***b*, **128***b*, **138***b*, **148***b*. The four CR boundary planes **118**, **128**, **138** **148**, have a height 'h' (FIG. **4**) in the Z direction of the coordinate axes in the figures and light reflected or transmitted within the CR **200** does not pass through the inward facing opaque surfaces **118***b*, **128***b*, **138***b*, **148***b*. Accordingly, an article (e.g., a cloaked article) located within the CR **200** is not visible to an observer viewing the cloaking assembly **10** in the +Y direction.

Still referring to FIGS. **1** and **2**, spaced apart from and oriented generally parallel (within +/−2°) to the four CR boundary planes **118**, **128**, **138** **148**, are half mirrors **115**, **125**, **135**, **145**, respectively. The half-mirrors **115**, **125**, **135**, **145** reflect a specific mode of visible light Specifically, each of the half mirrors **115**, **125**, **135**, **145** can be an s-polarizer half mirror or a p-polarizer half mirror. The half mirrors **115**, **125**, **135**, **145** can be in the form of a diffraction grating or thin film polarizer that reflects the s-mode of visible light and allows the p-mode of visible light to pass through (a p-polarization diffraction grating or thin film), or in the alternative, reflects the p-mode of visible light and allows the s-mode of the visible light to pass through (an s-polarization diffraction grating or thin film). It should be appreciated that the half mirrors **115**, **125** are both s-polarizer half mirrors or p-polarizer half mirrors and the half mirrors **135**, **145** are both s-polarizer half mirrors or p-polarizer half mirrors, i.e. the half mirrors **115**, **125** may be s-polarizer mirrors and the half mirrors **135**, **145** may be p-polarizer half mirrors; the half mirrors **115**, **125** may be p-polarizer mirrors and the half mirrors **135**, **145** may be s-polarizer half mirrors; or all of the half mirrors **115**, **125**, **135**, **145** may be s-polarizer half mirrors or p-polarizer half mirrors.

The four CR boundary planes **118**, **128**. **138** **148**, and the corresponding half mirrors **115**, **125**, **135**, **145**, may be part of four cloaking assembly components **110**, **120**, **130**, **140**, respectively. Each of cloaking assembly components **110**, **120**, **130**, **140** has an outward facing surface **112**, **122**, **132**, **142**, respectively, an inward facing surface **114**, **124**, **134**, **144**, respectively, an outer end surface **116**, **126**, **136**, **146**, respectively, and an inner side surface defined by the inward facing opaque surface **118***b*, **128***b*, **138***b*, **148***b*, respectively. The outward facing surfaces **112**, **132** form an object-side **102** of the cloaking device and the outward facing surfaces **122**, **142** form an image-side **104** of the cloaking device. One or more optical filters **125***a*, **125***b* may be positioned on or adjacent to the outward facing surface **122** and one or more optical filters **145***a*, **145***b* may be positioned on or adjacent to the outward facing surface **142**. The optical filter **125***a* is positioned to the right (+X direction) of the half-mirror **125**, the optical filter **125***b* is positioned to the left (−X direction) of the half-mirror **125**, the optical filter **145***a* is positioned to the left (−X direction) of the half-mirror **145**, and the optical filter **145***b* is positioned to the right (+X direction) of the half-mirror **145**. The one or more optical filters **125***a*, **125***b*, **145***a*, **145***b* may be quarter-wave plates that convert linearly polarized light into circularly polarized light, or in the alternative, the one or more optical filters **125***a*, **125***b*, **145***a*, **145***b* may be a quarter-wave plate and a linear polarizer that convert linearly polarized light of one mode, e.g., s-mode or p-mode, into circularly polarized light, and then convert the circularly polarized light into a different linearly polarized mode, e.g., p-mode or s-mode, respectively.

The CR boundary planes **118**, **138** are oriented at an angle θ_1 relative to the outward facing surfaces **112**, **132**, respectively, and the CR boundary planes **128**, **148** are oriented at an angle β_1 relative to the outward facing surfaces **122**, **142**, respectively. In embodiments, the angle θ_1 is equal to the angle β_1. In other embodiments, the angle θ_1 is not equal to the angle β_1. The half mirrors **115**, **135** are oriented at an angle θ_2 relative to the outward facing surfaces **112**, **132**, respectively, and the half mirrors **125**, **145** are oriented at an angle β_2 relative to the outward facing surfaces **122**, **142**, respectively. In embodiments, the angle θ_2 is equal to the angle β_2. In other embodiments, the angle θ_2 is not equal to the angle β_2. In embodiments, the angle θ_1 is equal to the angle θ_2 and the angle β_1 is equal to the angle β_2. For example, θ_1 and θ_2 can be generally equal to 45° (+/−1°), and β_1 and β_2 can be generally equal to 45° (+/−10).

The four cloaking assembly components **110**, **120**, **130**, **140** are transparent to incident light (both polarized and unpolarized) except for the half mirrors **115**, **125**, **135**, **145**, the outward facing mirror surfaces **118***a*, **128***a*, **138***a*, **148***a*, the inward facing opaque surfaces **118***b*, **128***b*, **138***b*, **148***b*, and optionally the outer end surfaces **116**, **126**, **136**, **146**. The four cloaking assembly components **110**, **120**, **130**, **140** can be made from any suitable transparent material, for example a transparent glass or a transparent plastic. In the alternative, the four cloaking assembly components **110**, **120**, **130**, **140** can be a structure, e.g. a frame, that holds the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145** in a desired orientation relative to each other with air or another gas present between the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145**. The frame may be a plurality of transparent glass or transparent plastic panes that hold the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145** in a desired orientation relative to each other with air or another gas present between the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145**. In embodiments, transparent glass or transparent plastic panes form the outward facing surfaces **112**, **122**, **132**, **142**, inward facing surfaces **114**, **124**, **134**, **144**, and outer end surfaces **116**, **126**, **136**, **146**, and hold the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145** in a desired orientation relative to each other with air or another gas present between the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145**.

The outer end surfaces **116**, **126**, **136**, **146** may be transparent, have an absorber layer disposed thereon or be a half-mirror. In embodiments, the outer end surfaces **116**, **126**, **136**, **146** are transparent. In other embodiments, the outer end surfaces **116**, **126**, **136**, **146** have an absorber layer disposed thereon that absorbs incident light from within the four cloaking assembly components **110**, **120**, **130**, **140**, and/or from outside the four cloaking assembly components

110, 120, 130, 140. The absorber layer may be made from any suitable material that absorbs approximately 90% (+/−10%) of incident light, illustratively including dark colored surfaces made of glass, polymers, metals, ceramics, composites, etc. In other embodiments, the outer end surfaces 116, 126, 136, 146 are half-mirrors such that one mode of incident light is reflected (e.g., s-polarized light or p-polarized light) and another mode of incident light is transmitted through the half mirror (e.g., p-polarized light or s-polarized light, respectively). In other embodiments, one or more of the outer end surfaces 116, 126, 136, 146 is transparent and one or more of the outer end surfaces 116, 126, 136, 146 has an absorber layer disposed thereon. In other embodiments, one or more outer end surfaces 116, 126, 136, 146 is transparent and one or more of the outer end surfaces 116, 126, 136, 146 is a half mirror. In other embodiments, one or more of the outer end surfaces 116, 126, 136, 146 has an absorber layer disposed thereon and one or more of the outer end surfaces 116, 126, 136, 146 is a half mirror. In other embodiments, one or more of the outer end surfaces 116, 126, 136, 146 is transparent, one or more of the outer end surfaces 116, 126, 136, 146 has an absorber layer disposed thereon, and one or more of the outer end surfaces 116, 126, 136, 146 is a half mirror.

While FIGS. 1-2 illustrate four cloaking assembly components 110, 120, 130, 140, it should be appreciated that the four CR boundary planes 118, 128, 138, 148, and the four half mirrors 115, 125, 135, 145 can be contained within any number of cloaking assembly components. For example, in embodiments, the cloaking assembly components 110 and 120 may be a single cloaking assembly component with no inward facing surface 114, 124, between the outward facing surfaces 112, 122, and the cloaking assembly components 130 and 140 may be a single cloaking assembly component with no inward facing surface 134, 144, between the outward facing surfaces 132, 142. In other embodiments, the cloaking assembly components 110 and 130 may be a single cloaking assembly component and the two cloaking assembly components 120 and 140 can be a single cloaking assembly component. In other embodiments, three of the four cloaking assembly components 110, 120, 130, 140 may be a single cloaking assembly component assembled with a remaining one of the cloaking assembly components 110, 120, 130, 140. For example, the three cloaking assembly components 110, 120, 130 may be a single cloaking assembly component assembled with the remaining cloaking assembly component 140. In other embodiments, the four cloaking assembly components 110, 120, 130, 140 may be a single cloaking assembly component.

Still referring to FIGS. 1-2, light 'lo' is reflected from an object 'O' (e.g., a target object) located on the object-side 102 of the cloaking device, travels in the −Y direction, and is incident on and transmitted through the outward facing surfaces 112, 132. The light lo reflected from the obscured portions of the object 'O' located directly behind the CR in the +Y direction is reflected by the outward facing mirror surfaces 118*a*, 138*a* in the +X and −X directions, respectively. The light lo reflected in the +X and −X directions is incident on the half mirrors 115, 135 respectively. As illustrated in FIG. 1, the half mirrors 115, 135 are p-polarization half mirrors that reflect the s-mode (ls) of the light lo and allow the p-mode (lp) of the light lo to pass through. The s-polarized light ls reflected from the half mirrors 115, 135 in the −Y direction is incident on the half mirrors 125, 145, respectively. The half mirrors 125, 145 are also p-polarization mirrors that reflect the s-polarized light ls traveling in the −Y direction into the −X and +X directions, respectively. The s-polarized light ls reflected in the −X and +X directions is incident on the outward facing mirror surfaces 128*a*, 148*a*, respectively, and the outward facing mirror surfaces 128*a*, 148*a* reflect the incident s-polarized light ls into the −Y direction. The s-polarized light reflected into the −Y direction by the outward facing mirror surfaces 128*a*, 148*a*, forms an image of the obscured portion of the target object located directly above the CR 200 in the +Y direction that is visible to an observer viewing the image-side 104 of the cloaking assembly 10. In embodiments, the optical filter 125*b*, the optical filter 145*b*, or both optical filters 125*b*, 145*b* may be positioned on or adjacent to the outward facing surfaces 122, 142, respectively, as described above, and may convert the s-polarized light reflected into the −Y direction by the outward facing mirror surfaces 128*a*, 148*a*, into circularly polarized light or p-polarized light. For example, the optical filter 125*b* the optical filter 145*b*, or both optical filters 125*b*, 145*b* may be quarter wave plates that convert the s-polarized light reflected into the −Y direction by the outward facing mirror surfaces 128*a*, 148*a* into circularly polarized light (not shown) before forming the image of the obscured portion of the target object 'O' located directly above the CR 200 in the +Y direction. In the alternative, the optical filter 125*b*, the optical filter 145*b*, or both optical filters 125*b*, 145*b* may be a quarter-wave plate and a linear polarizer that converts the s-polarized light reflected into the −Y direction by the outward facing mirror surfaces 128*a*, 148*a* into circularly polarized light (not shown) and then converts the circularly polarized light into p-polarized light before forming the image of the obscured portion of the target object 'O' located directly above the CR 200 in the +Y direction.

Light lo reflected from the visible portions of the target object 'O' not located directly behind the CR in the +Y direction is incident on and transmitted through the outward facing surfaces 112, 132. The transmitted light lo is incident on the p-polarization half mirrors 115, 135. The half mirrors 115, 135 reflect the s-mode is of the incident light lo in the +X and −X directions, respectively, and transmit the p-mode lp of the incident light lo in the −Y direction. The p-polarized light lp transmitted through the half mirrors 115, 135 will be incident on and be transmitted through the p-polarization half mirrors 125, 145, respectively, in the −Y direction. The p-polarized light lp transmitted in the −Y direction by the half mirrors 125, 145 forms an image of the visible portions of the target object O not located directly behind the CR 200 in the +Y direction that is visible to an observer viewing the cloaking assembly in the +Y direction. In embodiments, the optical filter 125*a*, the optical filter 145*a*, or both optical filters 125*a*, 145*a* may be positioned on or adjacent to the outward facing surfaces 122, 142, respectively, as described above, in order to convert the p-polarized light into circularly polarized light of s-polarized light. For example, the optical filter 125*a*, the optical filter 145*a* or both optical filters 125*a*, 145*a* may be quarter wave plates that convert the p-polarized light transmitted into the −Y direction by the half mirrors 125, 145 into circularly polarized light (not shown) before forming the image of the visible portions of the target object 'O' not located behind above the CR 200 in the +Y direction. In the alternative, the optical filter 125*a*, the optical filter 145*a*, or both optical filters 125*a*, 145*a* may be a quarter-wave plate and a linear polarizer that convert the p-polarized light reflected into the −Y direction by the outward facing mirror surfaces 128*a*, 148*a* into circularly polarized light (not shown) and then convert the circularly polarized light into s-polarized light before forming the image of the visible portions of the target object 'O' not

located directly above the CR **200** in the +Y direction. Accordingly, an image 'I' of the entire target object 'O' (both the obscured portion and the visible portions) is visible to the observer viewing the image-side **104** of the cloaking assembly **10**. While half mirrors **115**, **125**, **135**, **145** are described herein as p-polarization half mirrors, it should be appreciated that half mirrors **115**, **125**, **135**, **145** can be s-polarization half mirrors and the reflected and transmitted portions of the reflected light lo discussed above will be reversed. However, the human eye cannot distinguish between s-polarized light, p-polarized light or circularly polarized light and the image 'I' of the entire object 'O' will be visible to the human eye when an observer is viewing the image-side **104** of the cloaking assembly **10**. Also, it should be appreciated that the one or more of optical filters **125***a*, **125***b*, **145***a*, **145***b* may be positioned on or adjacent to outward facing surfaces **122**, **142** as described above such that only p-polarized light forms the image 'I', only s-polarized light forms the image 'I', only circularly polarized light forms the image 'I', only p-polarized light and circularly polarized light form the image 'I' or only s-polarized light and circularly polarized light form the image 'I'. Such manipulation of the polarized light reflected into the −Y direction by the outward facing mirror surfaces **128***a*, **128***a* and the polarized light transmitted in the −Y direction by the half mirrors **125**, **145** may assist an observer wearing polarized sunglasses in viewing the image-side **104** of the cloaking assembly **10**. Particularly, the one or more optical filters **125***a*, **125***b*, **145***a*, **145***b* ensure that polarized sunglasses that block p-polarized light or s-polarized light do not prevent an observer wearing such polarized sunglasses from seeing the entire target object 'O' when viewing the image-side **104** of the cloaking assembly **10**.

Referring now to FIGS. **1-4**, a top perspective view and a side view of a cloaking device according to embodiments (as discussed with respect to FIGS. **1-2**) are shown in FIGS. **3-4**, respectively. Specifically, FIG. **3** is a top perspective view of an article in the form of a column 'C' within the CR **200** of the cloaking assembly **10** and an automobile 'A' located behind the column C on the object-side **102** of the cloaking assembly **10** in the +Y direction. The column C has a height dimension in the Z direction (increasing height in the −Z direction) greater than the height h of the cloaking device. FIG. **4** is a side view from the +Y direction of the cloaking assembly **10** shown in FIG. **3** and shows the portion of the column C that is within the CR **200** is not visible and the automobile A located behind the column C in the +Y direction is visible to an observer viewing the cloaking assembly **10** in the +Y direction. Accordingly, the column C positioned within the CR **200** is not visible to an observer viewing the image-side **104** of the cloaking assembly **10** and an image of the entire automobile A (both the obscured portion and the visible portions) is visible to the observer viewing the image-side **104**. Although column C in FIGS. **3-4** is separate from the CR boundary planes **118**, **128**, **138**, **148**, i.e., column C is a separate object from the cloaking device **10**, it should be appreciated that column C may be structurally part of the cloaking device **10** and have an outer surface that provides or is equivalent to the CR boundary planes **118**, **128**, **138**, **148** with outward facing mirror surfaces **118***a*, **128***a*, **138***a*, **148***a*, respectively.

Referring now to FIGS. **1-5**, FIG. **5** shows embodiments of a cloaking assembly **12** with an enlarged CR **200**. Particularly, the cloaking assembly components **110**, **120**, **130**, **140** are arranged such that the cloaking assembly components **110**, **130** are spaced apart in the Y direction from the cloaking assembly components **120**, **140**, and a distance 'd' is between the inward facing surfaces **114**, **124**, and between the inward facing surfaces **134**, **144**. The area of the CR **200** in the X-Y plane is increased by the width 'w' times the distance d (w×d). The volume of the CR **200** is increased by the width w times the distance d times the height h (FIG. **4**) of the CR **200** (w×d×h). While FIG. **5** illustrates four cloaking assembly components **110**, **120**, **130**, **140**, it should be appreciated that the four CR boundary planes **118**, **128**, **138**, **148**, and the four half mirrors **115**, **125**, **135**, **145** can be contained within any number of cloaking assembly components. For example, in embodiments, the cloaking assembly components **110** and **130** may be a single cloaking assembly component and the two cloaking assembly components **120** and **140** can be a single cloaking assembly component.

As shown in the FIG. **5**, light lo is reflected from the target object O, travels in the −Y direction and is incident on and transmitted through the outward facing surfaces **112**, **132**. Light lo reflected from the obscured portions of the object located directly behind the CR in the +Y direction is reflected by the outward facing mirror surfaces **118***a*, **138***a* in the +X and −X direction, respectively. The reflected light lo in the +X and −X directions is incident on the half mirrors **115**, **135** respectively. The half mirrors **115**, **135** are p-polarization half mirrors and reflect the s-mode is of the light lo and transmit the p-mode lp of the light lo. The s-polarized light ls reflected by the half mirrors **115**, **135** in the −Y direction is incident on the half mirrors **125**, **145**, respectively. The half mirrors **125**, **145** are also p-polarization mirrors that reflect the s-polarized light ls traveling in the −Y direction into the −X and +X directions, respectively. The s-polarized light ls traveling in the −X and +X directions is incident on the outward facing mirror surfaces **128***a*, **148***a*, respectively, and the outward facing mirror surfaces **128***a*, **148***a* reflect the incident s-polarized light ls in the −Y direction. The s-polarized light reflected in the −Y direction by the outward facing mirror surfaces **128***a*, **148***a*, forms an image of the obscured portion of the object located behind the CR **200** in the +Y direction that is visible to an observer viewing the image-side **104** of the cloaking assembly **12**. Light lo reflected from the visible portions of the target object O not located behind the CR **200** in the +Y direction is incident on and transmitted through the outward facing surfaces **112**, **132**. The transmitted light lo is incident on the p-polarization half mirrors **115**, **135**, and the half mirrors **115**, **135** reflect the s-mode is of the incident light lo in the +X and −X directions, respectively, and transmit the p-mode lp of the incident light lo in the −Y direction. The p-polarized light lp transmitted through the half mirrors **115**, **135** in the −Y direction is incident on and transmitted through the p-polarization half mirrors **125**, **145**, respectively, in the −Y direction. The p-polarized light lp transmitted in the −Y direction through the half mirrors **125**, **145**, forms an image of the visible portions of the target object O not located behind the CR **200** in the +Y direction that is visible to an observer viewing the image side **104** of the cloaking assembly **12**. Accordingly, an image I of the entire target object O (both the obscured portion and the visible portions) is visible to an observer viewing the image-side **104** of the cloaking assembly **12**. It should be appreciated that half mirrors **115**, **125**, **135**, **145**, can be s-polarization half mirrors and the reflected and transmitted portions of the reflected light lo discussed above will be reversed. Also, it should be appreciated that the one or more of optical filters **125***a*, **125***b*, **145***a*, **145***b* may be included. However, the human eye cannot distinguish between s-polarized light, p-polarized light or circularly polarized light and the image I of the

entire object O will be visible to an observer viewing the image-side **104** of the cloaking assembly **12**.

Referring now to FIGS. **1-7**, a top perspective view and a side view of a cloaking device according to embodiments (as discussed with respect to FIG. **5**) are shown in FIGS. **6-7**, respectively. Specifically, FIG. **6** is a top perspective view of a first article in the form of a column 'C**1**' and a second article in the form of a column 'C**2**' within the CR **200** of the cloaking assembly **12** and the automobile 'A' located behind the columns C**1**, C**2** on the object-side **102** of the cloaking assembly **12** in the +Y direction. The column C**1** has a first height dimension in the Z direction and the column C**2** has a second height dimension that is greater (in the −Z direction) than the first height dimension of column C**1**. The first height dimension of column C**1** and the second height dimension of column C**2** are both greater than the height h of the cloaking assembly **12**. FIG. **7** is a side view from the +Y direction of the cloaking assembly **12** shown in FIG. **6** and shows the image-side **104**. Portions of column C**1** and column C**2** within the CR **200** are not visible and automobile A located behind column C**1** and column C**2** in the +Y direction is visible to an observer viewing the image-side **104** of the cloaking assembly **12**. Although columns C**1**, C**2** in FIGS. **6-7** are separate from the CR boundary planes **118**, **128**, **138**, **148**, i.e., columns C**1**, C**2** are separate objects from the cloaking device **12**, it should be appreciated that columns C**1**, C**2** may be structurally part of the cloaking device **12** and have an outer surface that provides or is equivalent to the CR boundary planes **118**, **128**, **138**, **148** with outward facing mirror surfaces **118***a*, **128***a*, **138***a*, **148***a*, respectively.

Referring to FIG. **8**, embodiments of a cloaking device that can display additional images in conjunction with the images depicted in FIGS. **1**, **4**, **5** and **7** are shown. Particularly, FIG. **8** shows an item in the form of the number '1' (item 1) and an item in the form of the number '2' (item 2) located adjacent to the outer end surfaces **126**, **146**, respectively, in the +X, −X directions, respectively. Light lo reflected from item 1 and item 2 is incident on and transmitted through the outer end surfaces **126**, **146** in the −X, +X directions, respectively. The light lo transmitted through the outer end surfaces **126**, **146** is incident on the half mirrors **125**, **145**, respectively. The half mirrors **125**, **145** (p-polarization half mirrors) transmit the p-mode lp of the light lo in the −X, +X directions, respectively, and reflect the s-mode is of the light lo into the −Y direction. The transmitted p-polarized light lp in the −X, +X directions is incident on the outward facing mirror surfaces **128***a*, **148***a*, respectively. The outward facing mirror surfaces **128***a*, **148***a*, reflect the incident p-polarized light lp into the −Y direction. The s-polarized light ls reflected by the half mirror **125** in the −Y direction forms a reversed '1' image on the right hand side of the outward facing surface **122** and the s-polarized light ls reflected by the half mirror **145** in the −Y direction forms a reversed '2' image on the left hand side of the outer facing surface **142**. The p-polarized light lp reflected by the outward facing mirror surface **128***a* into the −Y direction forms a reversed '1' image on the left hand side of the outward facing surface **122** and the p-polarized light lp reflected by the outward facing mirror surface **148***a* into the −Y direction forms a reversed '2' image on the right hand side of the outer facing surface **142**. It should be appreciated that the display of additional images as depicted in FIG. **8** in conjunction with images as depicted in FIGS. **1**, **4**, **5** and **7** can be used as part of a heads-up display, a warning system (signal) that an object is located on the object side of the cloaking device, etc.

Referring to FIGS. **1-10**, embodiments of a cloaking device with a cloaking assembly **14** having items in the form of '1', '2', '3', '4' adjacent to the outer end surfaces **126**, **146**, **116**, **136**, respectively are shown in FIG. **9**. FIG. **10** is a side view of the cloaking assembly **14** illustrated in FIG. **9** with reversed images of item 1 and item 2, in conjunction with the image of the automobile A, visible on the image-side **104** of the cloaking assembly **14**. It should be appreciated that items 1, 2, 3, 4 depicted in FIGS. **9-10** are shown for illustrative purposes only, i.e. the items 1, 2 in FIG. **9** could be oriented in the Y-Z plane in order to provide reversed images of items 1, 2 on the image side **104** (X-Z plane) in FIG. **10**. It should also be appreciated that reversed images of item 3 and item 4 can be formed or provided on the object-side **102** of the cloaking assembly **14** in a similar manner as the reversed images of item 1 and item 2 are formed on the image-side **104**.

Referring to FIGS. **1-8** and **11**, embodiments of a cloaking device that can selectively display images in conjunction with the images depicted in FIGS. **1**, **4**, **5** and **7** are shown. Particularly, FIG. **11** shows an item in the form of the number '1' and an item in the form of the number '2' located adjacent to the outer end surfaces **126**, **146**, respectively, in the +X, −X directions, respectively. Light lo from item 1 is incident on an s-polarizer **150**. The s-polarizer **150** allows the s-mode is of the incident light lo to pass through in the −X direction. The s-polarized light ls is incident on and reflected by the p-polarization half mirror **125** into the Y direction and no light is transmitted through or beyond the p-polarization half mirror **125** in the −X direction. Accordingly, a reversed image of item 1 is formed only on the right hand side of the outward facing surface **122**. The light lo from item 2 is transmitted through the outer end surface **146** in the +X direction and is incident on the p-polarization half mirror **145**. The p-polarization half mirror **145** transmits the p-mode lp of the incident light lo in the +X direction and reflects the s-mode is of the incident light lo in the −Y direction. The p-polarized light lp in the +X direction is incident on the outward facing mirror surface **148***a*. The outer facing mirror surface **148***a* reflects the incident p-polarized light lp in the −Y direction. The s-polarized light ls reflected by the half mirror **145** in the −Y direction forms a reversed item 2 image on the left hand side of the outer facing surface **142**. The p-polarized light lp reflected by the outer facing mirror surface **148***a* into the −Y direction provides a reversed item 2 image on the right hand side of the outer facing surface **142**.

Referring to FIGS. **1-8** and **11-13**, embodiments of a cloaking device with a cloaking assembly **16** having items in the form of '1' and '2' adjacent to the outer end surfaces **126**, **146**, respectively, and the s-polarizer **150** adjacent the outer end surface **126**, are shown in FIG. **12**. FIG. **13** is a side view of the cloaking assembly **16** illustrated in FIG. **12** with the reversed image of item 1 visible on the right hand side of the outer facing surface **122** of the cloaking assembly component **120** and the reversed image of item 2 visible on the left hand side and right hand side of the outward facing surface **142** of the cloaking assembly components **140** shown in conjunction with the image of the automobile A. It should be appreciated that items 1, 2 depicted in FIG. **12** are shown for illustrative purposes only, i.e. the items 1, 2 in FIG. **12** could be oriented in the Y-Z plane in order to provide the reversed images of items 1, 2 on the image-side (**104**) (X-Z plane) shown in FIG. **13**.

Referring to FIGS. **1-8** and **14**, another embodiment of a cloaking device that can selectively display additional images in conjunction with the images depicted in FIGS. **1**,

4, 5 and 7 is shown. Particularly, FIG. 14 shows an item in the form of the number '1' and an item in the form of the number '2' located adjacent to the outer end surfaces 126, 146, respectively, in the +X, −X directions, respectively. Light lo reflected from the item 1 is incident on a p-polarizer 152 which allows p-polarized light lp to pass through in the −X direction. The p-polarized light lp is incident on the p-polarization half mirror 125. The incident p-polarized light lp in the −X direction is transmitted through the p-polarization half mirror 125 in the −X direction and there is no s-polarized light is to be reflected by the p-polarization half mirror 125 in the −Y direction. The p-polarized light lp transmitted through the p-polarization half mirror 125 is incident on the outward facing mirror surface 128*a* and the outward facing mirror 128*a* reflects the p-polarized light lp into the −Y direction. Accordingly, a reversed image of item 1 is formed only on the left hand side of the outward facing surface 122. The light lo reflected from item 2 is transmitted through the outer end surface 146 in the +X direction and is incident on the p-polarization half mirror 145. The p-polarization half mirror 145 transmits the p-mode lp of the incident light lo in the +X directions and reflects the s-mode ls of the incident light lo into the −Y direction. The p-polarized light lp in the +X is incident on the outer facing mirror surface 148*a*. The outer facing mirror surface 148*a* reflects the incident p-polarized light lp into the −Y direction. The s-polarized light ls reflected by the half mirror 145 in the −Y direction forms a reversed 2 on the left hand side of the outer facing surface 142 and the p-polarized light lp reflected by the outer facing mirror surface 148*a* in the −Y direction forms a reversed 2 image on the right hand side of the outer facing surface 142.

Referring to FIGS. 1-8 and 14-16, embodiments of a cloaking device with a cloaking assembly 18 having items 1 and items 2 adjacent to the outer end surfaces 126, 146, respectively, and the p-polarizer 152 adjacent to the outer end surface 126, are shown in FIG. 15. FIG. 16 is a side view of the cloaking assembly 18 illustrated in FIG. 15 with the single reversed image of item 1 visible on the left hand side of the outer facing surface 122 of the cloaking assembly component 120 and the reversed image of item 2 visible on the left hand side and right hand side of the outward facing surface 142 of the cloaking assembly components 140 in conjunction with the image of the automobile A. It should be appreciated that items 1, 2 depicted in FIG. 15 are shown for illustrative purposes only, i.e. the items 1, 2 in FIG. 15 could be oriented in the Y-Z plane in order to provide the reverse images of items 1, 2 on the image-side 104 (X-Z plane) shown in FIG. 16.

Referring to FIGS. 1, 2, 5, 8-17, embodiments of an A-pillar of a vehicle being cloaked by a cloaking device are shown. Particularly, FIG. 17 shows a cloaking device 19 cloaking a portion of an A-pillar P of a vehicle V. A portion of the A-pillar P is positioned within a CR 200 (not shown) of the cloaking device 19 and a portion of the A-pillar P extends beyond the cloaking device and is covered with trim T. Illustrated outside of the vehicle V is a target object O in the form of pedestrian. A portion of the pedestrian O is visible through a side window of the vehicle V and a portion of the pedestrian is visible "through" the A-pillar P cloaked by the cloaking device 19. The cloaking device 19 redirects light reflected from the pedestrian O around the A-pillar P positioned within the CR 200 of the cloaking device 19 and forms an image I of the pedestrian O on an image-side 104 of the cloaking device 19 that is visible to an occupant of the vehicle V looking towards the pedestrian O. Accordingly, light from the pedestrian O appears to pass through the A-pillar P and a blind spot typically created by the A-pillar P is not present. In embodiments, the A-pillar P itself serves as the CR 200, i.e. the A-pillar P has an outer surface with one or more outer facing mirror surfaces that assist in redirecting light from the pedestrian) around the A-pillar P. It should be appreciated that cloaking of the A-pillar P with the cloaking device 19 and removing the blind spot produced by the A-pillar P is performed without the use of metamaterials, video images, cameras, sophisticated electronics, etc.

Referring to FIGS. 18-19, alternative embodiments of cloaking devices are shown. Specifically, FIG. 18 shows a cloaking device 20 with a circular CR 202 having an outer mirror surface 204 with half mirrors 206, 208 around the outer mirror surface 204 having a circular shape. In embodiments, the CR 202 is provided by an object to be cloaked itself, e.g., an A-pillar, that has an outer mirror surface 204. The cloaking device shown in FIG. 18 can increase the field of view for an observer viewing the cloaking device 20 in the +Y direction. FIG. 19 shows a cloaking device 30 with a circular CR 302 having an outer mirror surface 304 with half mirrors 306, 308 and optical components 310, 312 such as lenses. In embodiments, the CR 302 is provided by an object to be cloaked itself, e.g., an A-pillar, that has an outer mirror surface 304. The cloaking device shown in FIG. 19 allows for an external view from an object located behind the CR 302 (+Y direction) to be manipulated to increase a field of view or to normalize a distorted image.

The cloaking devices described herein may be used to cloak vehicle articles such as a vehicle A-pillar, and remove a "blind spot" caused by the vehicle article. It will be understood that the term "blind spot" as used herein refers to an area around the vehicle that cannot be directly observed by a driver while operating the vehicle. The terms "object," "article," and "item" may interchangeably refer to a visual object or image (2D or 3D) that reflects light or transmits light and the team "light from" may refer to "light reflected from" or "light transmitted from." The terms "generally," "approximately," and "about" may be utilized herein to represent the inherent degree of uncertainty that may be attributed to any quantitative comparison, value, measurement, or other representation. These terms are also utilized herein to represent the degree by which a quantitative representation may vary from a stated reference without resulting in a change in the basic function of the subject matter at issue.

While particular embodiments have been illustrated and described herein, it should be understood that various other changes and modifications may be made without departing from the spirit and scope of the claimed subject matter. Moreover, although various aspects of the claimed subject matter have been described herein, such aspects need not be utilized in combination. It is therefore intended that the appended claims cover all such changes and modifications that are within the scope of the claimed subject matter.

What is claimed is:

1. A cloaking device comprising:

an object-side and an image-side;

a cloaking region (CR) boundary plane having an outward facing mirror surface and an inward facing opaque surface;

a CR at least partially bounded by the inward facing opaque surface of the CR boundary plane;

a half mirror spaced apart from and generally parallel to the outward facing mirror surface;

wherein light from an object located on the object-side of the cloaking device and obscured by the CR is redi-

rected around the CR to form an image of the object on the image-side of the cloaking device such that the light from the object appears to pass through the CR.

2. The cloaking device of claim **1**, wherein the half mirror is selected from a p-polarization half mirror and an s-polarization half mirror.

3. The cloaking device of claim **1**, further comprising an article positioned within the CR, wherein the light from the object located on the object-side of the cloaking device and obscured by the CR is redirected around the CR and the article to form the image of the object on the image-side of the cloaking device such that the article appears transparent.

4. The cloaking device of claim **3**, wherein the article is a vehicle A-pillar.

5. The cloaking device of claim **1**, further comprising:

at least two CR boundary planes positioned non-planar to each other, each of the at least two CR boundary planes having an outward facing mirror surface and an inward facing opaque surface, the CR at least partially bounded by the inward facing opaque surfaces of the at least two CR boundary planes;

at least one quarter-wave plate positioned on or adjacent to the image side; and

at least two half mirrors spaced apart from and generally parallel to the outward facing mirror surfaces, respectively; such that a half mirror of the at least two half mirrors is spaced apart from and generally parallel to each of the outward facing mirror surfaces;

wherein the light from the object located on the object-side of the cloaking device and obscured by the CR is redirected around the CR by the at least two outward facing mirror surfaces and the at least two half mirrors, and the image of the object is formed on the image-side of the cloaking device such that the light from the object located on the object-side of the cloaking device appears to pass through the CR.

6. The cloaking device of claim **5**, wherein the at least two CR boundary planes are positioned orthogonal to each other.

7. The cloaking device of claim **6**, wherein the light from the object on the object-side of the cloaking device is reflected by a first outward facing mirror surface, a first half mirror positioned parallel to the first outward facing mirror surface, a second half mirror positioned orthogonal to the first half mirror, a second outward facing mirror surface positioned parallel to the second half mirror, and transmitted through the at least one quarter-wave plate before forming the image of the object on the image-side of the cloaking device.

8. The cloaking device of claim **7**, further comprising a vehicle article positioned within the CR, wherein the light from the object located on the object-side of the cloaking device and obscured by the CR is redirected around the CR and the vehicle article to form the image of the object on the image-side of the cloaking device and the vehicle article appears transparent.

9. The cloaking device of claim **5**, further comprising an end side, wherein light from an item positioned adjacent to the end side forms an image of the item on the image-side of the cloaking device.

10. A cloaking device for cloaking an article of a vehicle comprising:

a cloaking assembly comprising:

an object-side and an image-side;

at least two cloaking region (CR) boundary planes located at least partially between the object-side and the image-side, the at least two CR boundary planes positioned non-planar to each other and each of the at least two CR boundary planes having an outward facing mirror surface and an inward facing opaque surface;

a CR bounded by the inward facing opaque surfaces of the at least two CR boundary planes;

at least two half mirrors located at least partially between the object-side and the image-side, each of the at least two half mirrors spaced apart from and generally parallel to one of the outward facing mirror surfaces;

at least one quarter-wave plate positioned on or adjacent to the image side;

and

a vehicle article positioned within the CR;

wherein light from an object located on the object-side of the cloaking assembly and obscured by the CR is redirected around the CR and forms an image of the object on the image-side of the cloaking assembly such that the vehicle article appears to be transparent.

11. The cloaking device of claim **10**, wherein the vehicle article is a vehicle A-pillar.

12. The cloaking device of claim **10**, wherein the light from the object is reflected by a first outward facing mirror surface, a first half mirror oriented generally parallel to the first outward facing mirror surface, a second half mirror oriented generally orthogonal to the first half mirror and a second outward facing mirror surface oriented generally parallel to the second half mirror and transmitted through the at least one quarter-wave plate before forming the image on the image-side of the cloaking assembly.

13. The cloaking device of claim **12**, further comprising an end surface, wherein light from an item located adjacent to the end surface passes through the cloaking assembly and forms an image of the item on the image-side of the cloaking assembly.

14. The cloaking device of claim **13**, wherein a p-mode or an s-mode of the light from the item is reflected from the second half mirror before forming the image of the item on the image-side of the cloaking assembly.

15. The cloaking device of claim **13**, wherein a p-mode or an s-mode of the light from the item is transmitted through the second half mirror and reflected by the second outward facing mirror surface before forming the image of the item on the image-side of the cloaking assembly.

16. A cloaking device comprising:

four cloaking region (CR) boundary planes positioned non-planar to each other, each of the four CR boundary planes having an outward facing mirror surface and an inward facing opaque surface;

a CR bounded by the inward facing opaque surfaces of the four CR boundary planes;

an article located at least partially within the CR;

four half mirrors spaced apart from and generally parallel to the outward facing mirror surfaces, respectively, such that a half mirror of the four half mirrors is spaced apart from and generally parallel to each of the outward facing mirror surfaces;

wherein light from an object on an object-side of the cloaking device is redirected around the CR and appears as an image on an image-side of the cloaking device and is visible to an observer viewing the image-side of the cloaking device, and wherein the article within the CR is not visible to the observer viewing the image-side of the cloaking device such that the article within the CR appears transparent to the observer viewing the image-side of the cloaking device.

17. The cloaking device of claim 16, wherein the light from the object is reflected by a first of the outward facing mirror surfaces, a first of the outward facing mirror surfaces, a first of the four half mirrors oriented generally parallel to the first outward facing mirror surface, a second half mirror oriented generally orthogonal to the first half mirror and a second outward facing mirror surface oriented generally parallel to the second half mirror before forming the image on the image-side of the cloaking device.

18. The cloaking device of claim 17, wherein the article is a vehicle A-pillar.

19. The cloaking device of claim 18, further comprising an end side, wherein light from an item located adjacent to the end side is reflected by at least one of the second half mirror and the second outward facing mirror surface and forms an image of the item on the image-side of the cloaking device.

20. The cloaking device of claim 19, wherein the image of the item is selectively formed on the image-side of the cloaking device.

* * * * *